PRODUCTION OF N^{17} *NUCLEI BY BOMBARDMENT OF SOME ELEMENTS WITH HEAVY IONS*

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Submitted to JETP editor May 9, 1961, resubmitted August 9, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 1365-1369 (November, 1961)

A new method of investigating the transfer reactions by detecting the delayed neutron activity is proposed. Li, C, Al, and Cu targets were bombarded with N^{15}, O^{16}, and Ne^{22} ions using the accelerator of the Joint Institute for Nuclear Research in Dubna. Production of N^{17} nuclei was observed in all cases. The cross sections for the production of N^{17} by bombarding the above-mentioned targets with 95 Mev N^{15} ions were measured, as well as the yield of N^{17} from thick C, Al, and Cu targets irradiated with O^{16} and Ne^{22} ions.

AMONG the many types of reactions involving heavy ions, those occuring in the peripheral collisions of the incident nuclei with those of the target are of special interest. A direct transfer of a single nucleon or even of a whole group of nucleons from one nucleus to the other, without passing through the stage of the compound nucleus, may occur in such collisions. Such reactions have lately been called transfer reactions. Since such processes occur on the surface of the nuclei, we can expect their study to reveal the state of the peripheral nucleons.

The capture of neutrons, protons, and α particles has been observed in a number of experiments.[1-13] The capture of two neutrons was observed in[14], and possibly in[15], and the transfer of larger fragments in[16].

The detection of β-active reaction products is usually employed in the study of transfer reactions. In the present experiment an attempt has been made to study transfer reactions by another experimental method.

1. PRINCIPLE OF THE METHOD

One of the possible transfer reaction products of the irradiation of nuclei by beams of various heavy ions is N^{17}, which emits delayed neutrons with a half-life of 4.15 sec.[17,18] This neutron activity, unique among all nonfissionable nuclei, enables us to overcome the problem of background radioactivity from other reaction products, which is especially important in the study of the reactions having a small cross section.

Other neutron-active nuclei can also be produced in the reactions, such as Li^9 ($T_{1/2}$ = 0.16 sec)[17] and C^{16} ($T_{1/2}$ = 0.74 sec).[19] However, in view of the marked difference in the half-lives, the identification is not difficult. Moreover, the proposed method enables us to find new nuclei emitting delayed neutrons.

The method was first proposed for studying the two-neutron capture by the N^{15} nucleus:

$$A_Z + N^{15} = (A-2)_Z + N^{17}.$$

However, from the experiment carried out, it is clear that the method can be successfully applied to the study of other transfer reactions as well.

2. APPARATUS AND PROCEDURE

The experiments were carried out using the internal beam of the heavy-ion cyclotron of the Joint Institute for Nuclear Research. Proportional BF_3 counters were used to detect the neutrons from the N^{17} nuclei. The counters were placed in a 140×250×340 mm lucite moderator (Fig. 1) with a hollow central part containing the target. The assembly was placed in a copper casing cooled by water. The casing also contained an emitter follower. A graphite beam collimator was placed before the casing, which helped to guide the beam to the casing. (The collimator is omitted in the figures.) Eight proportional counters 2 cm in diameter and 25 cm long were placed in two groups in the upper and lower parts of the assembly. Since all counters had practically identical characteristics, their cathodes were connected together and were supplied with the same high voltage.

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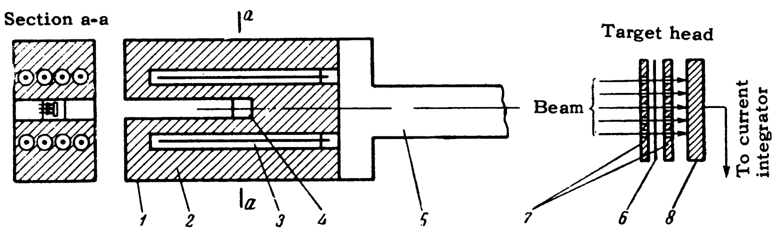

FIG. 1. General view of the detector: 1 – copper casing, 2 – lucite moderator, 3 – BF_3 counters, 4 – target head, 5 – probe support, 6 – aluminum foil, 7 – collimator grid, 8 – target current collector.

A block diagram of the apparatus is shown in Fig. 2. The pulse produced in any of the counters was fed to the emitter follower and transmitted to a linear amplifier and amplitude discriminator and to a 13-channel time analyzer. A scaler was connected in parallel to the analyzer. It was found by trial and error that the most satisfactory counter operation was at 3000 v, with an amplifier gain equal to 400 and a discriminator level of 25 v. Under these conditions, the efficiency of the detector amounted to 0.5% for the polonium-beryllium source in the position of the target. The background, in the presence of 2 mC of Co^{60}, amounted to 2 pulses per minute.

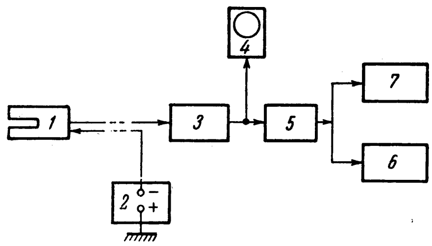

FIG. 2. Block diagram of the apparatus: 1 – neutron detector, 2 – high-voltage supply, 3 – linear amplifier, 4 – oscilloscope, 5 – amplitude discriminator, 6 – time analyzer, 7 – scaler.

Since the proportional neutron counters had to operate in the magnetic field of the cyclotron, a preliminary experiment was carried out to determine the influence of the magnetic field on their counting rate. It was found that a magnetic field perpendicular to the counter axis does not change its counting properties.

In order to test the method, thick targets of Li_2CO_3, aluminum, copper, and graphite were irradiated by $N^{15(3+)}$ ions and $O^{16(3+)}$ ions. The graphite was also irradiated by $Ne^{22(4+)}$ ions. The shape of the target is shown in Fig. 1.

In the irradiation of the aluminum and copper, all parts of the target head exposed to the beam were made of one material. In the irradiation of graphite with Li_2CO_3, a 15 μ aluminum foil was used to stop singly charged ions. In the two latter cases, the contribution from the "impurity" elements was estimated from the data obtained with aluminum and copper.

The beam intensity, measured using a current integrator, varied from 0.05 μa to 1 μa. The energy of the bombarding ions was determined from the beam radius. Pulsed operation of the cyclotron was employed in the measurements. Since the half-life of N^{17} is 4.15 sec, the target was irradiated for 30 sec. The high-frequency voltage on the dee was then switched off, and the neutron activity was counted for 30 sec.

At the moment the beam was switched off, the counter voltage was automatically switched on, and the time analyzer and scaler began counting. The counter voltage was removed when the beam was switched on.

For each value of ion energy, 4—5 irradiation cycles were carried out. Since the vertical distribution of the ion beam varied with the radius

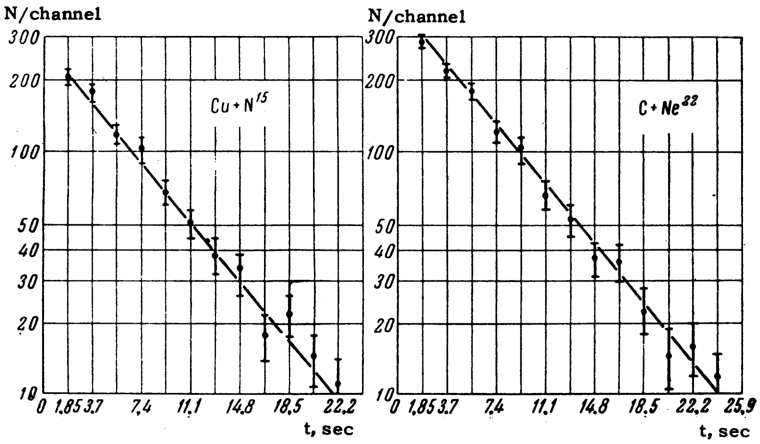

FIG. 3. Typical curves of neutron activity decay for the Cu + N^{15} and C + Ne^{22} reactions.

Table I. Effective cross section for the $N^{15} \rightarrow N^{17}$ reaction for 95 Mev energy of N^{15} ions, and the value of Q* for these reactions

Target	σ, mb	Q, Mev	Target	σ, mb	Q, Mev
Li_2CO_3	4	— 4.40**	Al	0.1	—16.05
Cu	1	{ —10.85*** { — 9.36	C	0.01	—23.69

*The Q values were calculated from the isotope masses using the Wapstra tables.[21]

**Q was calculated for Li^7, and the contribution of C and O was neglected.

***Q values for Cu^{63} and Cu^{65} respectively.

(influence of the magnetic focusing of the cyclotron), a graphite beam collimator was placed before the experimental assembly 24 cm ahead of the target (Fig. 1). The background measurements carried out showed that the yield from the graphite collimator amounted to not more than 10% of the effect when the whole beam fell only on the upper or lower part of the collimator. During irradiation, only a small part of the beam fell on the collimator, so that the background from the collimator could be neglected.

3. RESULTS OF THE MEASUREMENTS

A. Irradiation with N^{15} ions. In order to observe the two neutron-capture reactions, Li, C, Al, and Cu were irradiated. Lithium (natural isotope mixture) was used in the form of Li_2CO_3; the carbon target was made of pure graphite. In all cases, the onset of neutron activity was observed, which decreased with a half-life of 4 sec. A typical picture of the decay is shown in Fig. 3. The effective reaction cross section was calculated from the yield from a thick target (see Table I). The range of N^{15} necessary for this calculation was computed using formulas given by Northcliffe.[20]

Table II. Yield of N^{17} nuclei per bombarding particle in the irradiation of C, Al, and Cu targets by O^{16} ions of 95 Mev and Ne^{22} ions of 184 Mev

Target	Bombarding ion	
	O^{16}	Ne^{22}
C	$1 \cdot 10^{-10}$	$2 \cdot 10^{-8}$
Al	$5 \cdot 10^{-10}$	—
Cu	$6 \cdot 10^{-9}$	—

B. Irradiation with O^{16} and Ne^{22} ions. The onset of neutron activity with a 4-sec half-life was also observed upon irradiation of the above-mentioned targets with O^{16} ions and of a graphite target with Ne^{22} ions. The yields of these reactions are shown in Table II. It can be assumed that the N^{17} nucleus, in these cases, is produced as a result of reactions in which the O^{16} nucleus transfers a proton to the target nucleus and captures neutrons from it. The Ne^{22} nucleus transfers a proton and an α particle. The possibility cannot be excluded that N^{17} is produced on light nuclei as one of the decay fragments of a strongly excited compound nucleus.

To obtain a final answer to this question, additional and more detailed experiments are necessary. However, apart from the final solution of this problem, the results obtained show that the neutron activity of N^{17} can successfully be used for the study of a wide range of transfer reactions.

In conclusion, the authors consider it their pleasant duty to thank all members of the cyclotron team who ensured a trouble-free operation of the machine, and especially to Iu. Ts. Oganesyan, Yu. V. Lobanov, A. S. Pasyuk, B. N. Markov, I. A. Shelaev, and V. A. Shchegolev. We would also like to thank A. F. Linev and L. Kumpf for the design and construction of the time analyzer, and A. N. Filipson for testing the vacuum probe.

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Translated by H. Kasha
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